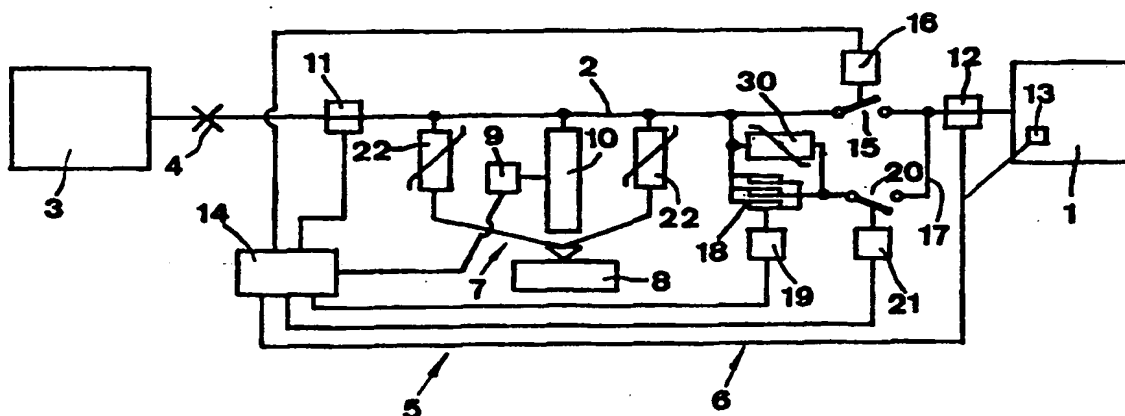




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(54) Title: DEVICE AND METHOD RELATING TO PROTECTION OF AN OBJECT AGAINST OVER-CURRENTS COMPRISING OVER-CURRENT REDUCTION



(57) Abstract

This invention is related to a device and a method for protection, in an electric power plant, of an object (1) against over-currents from a network (3) or another equipment included in the high voltage plant, the device comprising a switching device (4) in a line (2) between the object and the network/equipment. The line (2) between the object and the network/equipment is connected to an arrangement (5) reducing over-currents towards the object (1), said arrangement (5) being activatable for over-current reduction with the assistance of an arrangement (11-13) detecting over-current conditions within a time period substantially shorter than the breaktime of the switching device (4).

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Device and method relating to protection of an object
against over-currents comprising over-current reduction.

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FILED OF THE INVENTION AND PRIOR ART

This invention is related to a device in an electric power
plant for protection of an object connected to an electric
15 power network or another equipment in the electric power
plant from fault-related over-currents, the device com-
prising a switching device in a line between the object
and the network/equipment. In addition, the invention
includes a method for protecting the object from over-
20 currents.

The electric object in question is preferably formed by an
apparatus having a magnetic circuit requiring protection
against fault-related over-currents, i.e. in practice
25 short-circuit currents. As an example, the object may be a
transformer or reactor. The present invention is intended
to be applied in connection with medium or high voltage.
According to IEC norm, medium voltage refers to 1-72,5 kV
whereas high voltage is >72,5 kV. Thus, transmission, sub-
30 transmission and distribution levels are included.

In prior power plants of this nature one has resorted to,
for protection of the object in question, a conventional
circuit-breaker (switching device) of such a design that
35 it provides galvanic separation on breaking. Since this
circuit breaker must be designed to be able to break very

high currents and voltages, it will obtain a comparatively bulky design with large inertia, which reflects itself in a comparatively long break-time. It is pointed out that the over-current primarily intended is the short-circuit current occurring in connection with the protected object, for instance as a consequence of faults in the electric insulation system of the protected object. Such faults means that the fault current (short-circuit current) of the external network/equipment will tend to flow through the arc created in the object. The result may be a very large breakdown. It may be mentioned that for the Swedish power network, the dimensioning short-circuit current/fault-current is 63 kA. In reality, the short-circuit current may amount to 40-50 kA.

A problem with said circuit-breaker is the long-break time thereof. The dimensioning break-time (IEC-norm) for completely accomplished breaking is 150 milliseconds (ms). It is associated to difficulties to reduce this break-time to less than 50-130 ms depending upon the actual case. The consequence thereof is that when there is a fault in the protected object, a very high current will flow through the same during the entire time required for actuating the circuit-breaker to break. During this time the full fault current of the external power network involves a considerable load on the protected object. In order to avoid damage and complete breakdown with respect to the protected object, one has, according to the prior art, constructed the object so that it manages, without appreciable damage, to be subjected to the short-circuit current/fault current during the break-time of the circuit breaker. It is pointed out that a short-circuit current (fault current) in the protected object may be composed of the own contribution of the object to the fault current and the current addition emanating from the network/equipment. The own contribution of the object to the fault current is not

influenced by the functioning of the circuit-breaker but the contribution to the fault current from the network/equipment depends upon the operation of the circuit breaker. The requirement for constructing the protected
5 object so that it may withstand a high short-circuit current/fault current during a considerable time period means substantial disadvantages in the form of more expensive design and reduced performance.

10 Present day transformers and reactors rely, with respect to protection, on their own inherent transient current limiting ability, as a consequence of high inductance, in addition to the function of the conventional circuit
15 breaker described above. Although the present invention is applicable on such conventional transformers and reactors, it is with special advantage applicable on new inventive transformers or reactors, which will be discussed more in detail hereunder and which by their design present
20 a lower inductance/impedance than conventional transformers and reactors and which therefore cannot constitute, to an equally high degree, an inductively current limiting unit involving an own protection against over-currents as well as a protection for electric units located before and
25 after respectively the transformer/reactor. In such non conventional transformers and reactors, it is of course particularly important that the protection device operates rapidly to delimit the damaging effect of the fault.

In order to simplify the understanding, a conventional
30 power transformer will be explained hereunder. What is stated is in all essentials also applicable with respect to reactors. Reactors may be designed as single-phase and three-phase reactors. As regards insulation and cooling there are, in principle, the same embodiments as for
35 transformers. Thus, air-insulated and oil-insulated, self-cooled, pressure-oil-cooled, etc., reactors are available.

Although reactors have one winding (per phase) and may be designed both with and without an iron core, the following description is to a large extent relevant also to reactors.

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A conventional power transformer comprises a transformer core, in the following referred to as a core, often of laminated oriented sheet, usually of silicone iron. The core comprises a number of core limbs, connected by yokes which together form one or more core windows. Transformers with such a core are often referred to as core transformers. Around the core limbs there are a number of windings which are normally referred to as primary, secondary and control windings. As far as power transformers are concerned, these windings are practically always concentrically arranged and distributed along the length of the core limbs. The core transformer normally has circular coils as well as a tapering core limb section in order to fill up coils as closely as possible.

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Sometimes also other types of core designs occur, for example those which are included in so called shell-type transformers. These have as a rule rectangular coils and a rectangular limb section.

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Conventional power transformers, in the lower part of the power range in question, namely from 1 VA to the 1000 MVA range, are sometimes designed with air-cooling to carry away the unavoidable inherent losses. For protection against contact, and possibly for reducing the external magnetic field of the transformer, it is often provided with an outer casing provided with ventilation openings.

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Most of the conventional power transformers, however, are oil-cooled. One of the reasons therefore is that the oil has the additional very important function as insulating

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medium. An oil-cooled and oil-insulated conventional power transformer must therefor be surrounded by an external tank on which, as will be clear from the description below, very high demands are placed.

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Conventional oil-insulated power transformers are also manufactured with water-cooling of the oil.

10 The following part of the description will for the most part refer to conventional oil filled power transformers.

The windings mentioned above are formed from one or more series-connected coils built up of a number of series-connected turns. In addition, the coils are provided with a special device to allow switching between the terminals of the coils. Such a device may be designed for changeover with the aid of screw joints or more often with the aid of a special switch which is operable in the vicinity of the tank. In the event that switching can take place for a transformer under voltage, the changeover switch is referred to as an on-load tap changer whereas otherwise it is referred to as a de-energized tap changer.

25 Regarding oil-cooled and oil-insulated power transformers in the upper power range, the breaking element of the on-load tap changers are placed in special oil-filled containers with direct connection to the transformer tank. The breaking elements are operated purely mechanically via a motor driven rotating shaft and are arranged so as to obtain a fast movement during the switching when the contact is open and a slower movement when the contact is to be closed. The on-load tap changer as such, however, are placed in the actual transformer tank. During the operation, arcing and sparking arise. This leads to degradation of the oil in the containers. In order to obtain less arcs and hence also less formation of soot and less wear on the

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contacts, the on-load tap changers are normally connected to the high-voltage side of the transformer. This is due to the fact that the currents which need to be broken and connected, respectively, are smaller on the high-voltage side than if the on-load tap changers were to be connected to the low-voltage side. Failure statistics of conventional oil-filled power transformers show that it is often the on-load tap changers which give rise to faults.

10 In the lower power range of oil-cooled and oil-insulated power transformers, both the on-load tap changers and their breaking element are placed inside the tank. This means that the above-mentioned problems with degradation of the oil because of arcs during operation etc. effect
15 the whole oil system.

A considerable difference between a conventional power transformer and such a non-conventional power transformer intended with the invention refers to the conditions with
20 respect to insulation. For that reason it will be described more in detail with reference to Fig 1 why the insulation system is built as it is in conventional power transformers.

25 From the point of view of applied or induced voltage, it can broadly be said that a voltage which is stationary across a winding is distributed equally onto each turn of the winding, that is the turn voltage is equal on all turns.

30 From the point of view of electric potential, however, the situation is completely different. One end of a winding, assuming the lower end of a winding according to Fig 6, is normally connected to earth. This means, however, that
35 the electric potential of each turn increases linearly from practically zero in the turn which is nearest the

earth potential up to a potential in the turns which are at the other end of the winding which correspond to the applied voltage.

5 In Fig 6, which in addition to a winding 27 comprises a core 28, a simplified and fundamental view of the equipotential lines 29 with respect to the electric field distribution is shown for a conventional winding for a case
10 where the lower part of the winding is assumed to be at earth potential. This potential distribution determines the composition of the insulation system, since it is necessary to have sufficient insulation both between adjacent turns of the winding and between each turn and earth. Thus, the Figure shows that the upper part of the winding
15 is subjected to the highest insulation loads. The design and location of a winding relative to the core are in this way determined substantially by electric field distribution in the core window.

20 The turns in an individual coil are normally brought together into a geometrical coherent unit, physically delimited from the other coils. The distance between the coils is also determined by the dielectric stress which may be allowed to occur between the coils. Thus, this means that
25 a certain insulation distance is also required between the coils. According to the above, sufficient insulation distances are also required to the other electrically conducting objects which are within the electric field from the electric potential occurring locally in the coils.

30 Thus, it is clear from the above description that for the individual coils, the voltage difference internally between physically adjacent conductor elements is relatively low whereas the voltage difference externally in relation
35 to other metal objects, including the other coils, may be relatively high. The voltage difference is determined by

the voltage induced by magnetic induction as well as by the capacitively distributed voltages which may arise from a connected external electrical system on the external connections of the transformer. The voltage types which
5 may enter externally comprise, in addition to operating voltage, lightening over-voltages and switching over-voltages.

10 In the current leads of the coils, additional losses arise as a result of the magnetic leakage field around the conductor. To keep these losses as low as possible, especially for power transformers in the upper power range, the conductors are normally divided into a number of conductor element, often referred to as strands, which are
15 parallel-connected during operation. These strands must be transposed according to such a pattern that the induced voltage in each strand becomes as identical as possible and so that the difference in induced voltage between each pair of strands becomes as small as possible for inter-
20 nally circulating current components to be kept down at a reasonable level from the loss point of view.

When designing transformers according to the prior art, the general aim is to have as large a quantity of conductor material as possible within a given area limited by
25 the so called transformer window, generally described as having as high a fill factor as possible. The available space shall comprise, in addition to the conductor material, also the insulating material associated with the
30 coils, partly internally between the coils and partly to other metallic components including the magnetic core.

The insulation system, partly within a coil/winding and partly between coils/windings and other metal parts, is
35 normally designed as a solid cellulose- or varnish-based insulation nearest the individual conductor element, and

outside of this as solid cellulose and liquid, possibly also gaseous, insulation. Windings with insulation and possible bracing parts in this way represent large volumes which will be subjected to high electric field strengths which arise in and around the active electromagnetic parts of the transformer. To be able to predetermine the dielectric stresses which arise and achieve a good dimensioning with a minimum risk of breakdown, good knowledge of the properties of insulating materials is required. It is also important to achieve such a surrounding environment that it does not change or reduce the insulating properties.

The currently predominant insulation system for high-voltage conventional power transformers comprises cellulose material as the solid insulation and transformer oil as the liquid insulation. The transformer oil is based on so-called mineral oil.

Transformer oil has a dual function since, in addition to the insulating function, it actively contributes to cooling of the core, the winding, etc, by removal of the loss heat of the transformer. Oil cooling requires oil pump, an external cooling element, and expansion coupling etc.

The electrical connection between the external connections of the transformer and the immediately connected coils/windings is referred to as a bushing aiming at a conductive connection through the tank which, in the case of oil-filled power transformers, surround the actual transformer. The bushing is also a separate component fixed to the tank and is designed to withstand the insulation requirements being made, both on the outside and the inside of the tank, while at the same time it

should withstand the current loads occurring and the ensuing current forces.

5 It should be pointed out that the same requirements for the insulation system as described above regarding the windings also apply to the necessary internal connections between the coils, between bushings and coils, different types of change-over switches and the bushings as such.

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All the metallic components inside a conventional power transformer are normally connected to a given ground potential with the exception of the current-carrying conductors. In this way, the risk of an unwanted, and difficult-to-control, potential increase as a result of capacity voltage distribution between current leads at high potential and ground is avoided. Such an unwanted potential increase may give rise to partial discharges, so-called corona. Corona may be revealed during the normal acceptance tests, which partially are performed, compared with rated data, increased voltage and frequency. Corona may give rise to damage during operation.

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The individual coils in a transformer must have such a mechanical dimensioning that they may withstand any stresses occurring as a consequence of currents arising and the resultant current forces during a short-circuit process. Normally, the coils are designed such that the forces arising are absorbed within each individual coil, which in turn may mean that the coil can not be dimensioned optimally for its normal function during normal operation.

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Within a narrow voltage and power range of oil-filled power transformers, the windings are designed as so-called sheet windings. This means that the individual conductors mentioned above are replaced by thin sheets.

5 Sheet-wound power transformers are manufactured for voltages of up to 20-30 kV and powers of up to 20-30 MW.

The insulation system of conventional power transformers within the upper power range requires, in addition to a

10 relatively complicated design, also special manufacturing measures to utilize the properties of the insulation system in the best way. For a good insulation to be obtained, the insulation system shall have a low moisture content, the solid part of the insulation shall be well

15 impregnated with the surrounding oil and the risk of remaining "gas" pockets in the solid part must be minimal. To ensure this, a special drying and impregnating process is carried out on a complete core with windings before it is lowered into a tank. After this drying and

20 impregnating process, the transformer is lowered into the tank which is then sealed. Before filling of oil, the tank with the immersed transformer must be emptied of all air. This is done in connection with a special vacuum treatment. When this has been carried out, filling

25 ing of oil takes place.

To be able to obtain the promised service life, etc, of a conventional oil-filled transformer, pumping out to almost absolute vacuum is required in connection with

30 the vacuum treatment. Thus, this presupposes that the tank which surrounds the transformer is designed for full vacuum, which entails a considerable consumption of material and manufacturing time.

35 If electric discharges occur in an oil-filled power transformer, or if a local considerable increase of the

temperature in any part of the transformer occurs, the oil is disintegrated and gaseous products are dissolved in the oil. The transformers are therefore normally provided with monitoring devices for detecting of gas dissolved in the oil.

For weight reasons, large power transformers are transported without oil. In situ installation of the transformer at a customer requires, in turn, renewed vacuum treatment. In addition, this is a process which has to be repeated each time the tank is opened for some action or inspection.

It is obvious that these processes are very time-consuming and cost-demanding and constitute a considerable part of the total for manufacturing and repair while at the same time requiring access to extensive resources.

The insulating material in a conventional power transformer constitutes a large part of the total volume of the transformer. For a conventional power transformer the upper power range, oil quantities in the order of magnitude of several tens of cubic meters of transformer oil are not unusual. The oil which exhibits a certain similarity to diesel oil is thinly fluid and exhibits a relatively low flash point. Thus, it is obvious that oil together with the cellulose constitutes a non-negligible fire hazard in the case of unintentional heating, for example at an internal flashover, and a resultant oil spillage.

It is also obvious that, especially in conventional oil-filled power transformers, there is a very large transport problem. A conventional oil-filled power transformer in the upper power range may have a total oil volume of 40-50 cubic meters and may have a weight of up to 30-40 tons.

For conventional power transformers in the upper power range, transport often occurs with a tank without oil. It happens that the external design of the transformer must be adapted to the current transport profile, that is for any passage of bridges, tunnels etc..

Here follows a short summary of what can be described as limitation and problem areas according to prior art with respect to oil-filled power transformers:

An oil-filled conventional power transformer

- comprises an outer tank which is to house a transformer comprising a transformer core with coils, oil for insulation and cooling, mechanical bracing devices of various kinds etc. Very large mechanical demands are placed on the tank, since, without oil but with a transformer, it shall be capable of being vacuum-treated to practically full vacuum. The need for an external tank require very extensive manufacturing and testing processes. Furthermore, the tank means that external measures of the transformer become much larger than for a so called "dry" transformer for the same power. The larger external measures also normally entail considerable transport problems.

- normally comprises a so called pressure-oil-cooling. This cooling method requires access to an oil pump, an external cooling element, an expansion vessel and an expansion coupling etc.

- comprises an electrical connection between the external connections of the transformer and the immediately connected coils/windings in the form of a bushing fixed to the tank. The bushing is designed to withstand any insulation requirements made, both regarding the outside and the inside of the tank.

5 - comprises coils/windings whose conductors are divided into a number of conductor elements, strands, which have to be transposed in such a way that the voltage induced in each strand becomes as identical as possible and such that the difference in induced voltage between each pair of strands becomes as small as possible.

10 - comprises an insulation system, partly within a coil/winding and partly between coils/windings and other metal parts, which system is designed as a solid cellulose or varnish-based insulation nearest the individual conductor element and, outside of this, solid cellulose and a liquid, possibly also gaseous, insulation. In addition, it is extremely important that the insulation system exhibits a very low moisture content.

20 - comprises as an integrated part an on-load tap changer, surrounded by oil and normally connected to the high voltage winding of the transformer for voltage control.

25 - involves a non-negligible fire hazard in connection with internal partial discharges, so called corona, sparking in on-load tap changers and other fault conditions.

30 - comprises normally a monitoring device for monitoring gas dissolved in the oil, which occurs in case of electrical discharges therein and in case of local increases of the temperature.

- may result, in the event of damage or accident, in oil spillage leading to extensive environmental damage.

OBJECT OF THE INVENTION

The primary object of the present invention is to devise ways to design the device and the method so as to achieve better protection for the object and, accordingly, a reduced load on the same, a fact which means that the object itself does not have to be designed to withstand a maximum of short-circuit currents/fault currents during relatively long time periods.

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A secondary object with the invention is to design the protection device and method such that an adequate protection is achieved for electric objects in the form of transformers and reactors, the design of which is based upon non-conventional design principles, which may mean that the design does not have the same resistance to fault-related over-currents, internal as well as external, as the conventional present day conventional transformers and reactors. However, the invention is of course also intended to be applicable in connection with conventional transformers and reactors.

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SUMMARY OF THE INVENTION

According to the invention, the object indicated above is achieved in that the line between the object and the switching device is connected to an over-current reducing arrangement, which is actuatable for over-current reduction with assistance of an over-current conditions detecting arrangement within a time-period substantially less than the break-time of the switching device.

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Thus, the invention is based upon the principle not to rely for breaking purposes only upon a switching device which finally establishes galvanic separation, but instead use a rapidly operating over-current reducing arrangement,

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which, without effecting any real breaking of the over-current, nevertheless reduces the same to such an extent that the object under protection will be subjected to substantially reduced strains and, accordingly, a smaller amount of damages. The reduced over-current/fault current means, accordingly, that when the switching device establishes galvanic separation, the total energy injection into the protected object will have been much smaller than in absence of the over-current reducing arrangement.

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According to a preferred embodiment of the invention, the over-current reducing arrangement is designed as comprising an over-current diverter for diversion of over-currents to earth or otherwise another unit having a lower potential than the network/equipment.

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According to a particularly preferred embodiment of the invention, measures have been taken to obtain a reduction of the time-period, during which the current already reduced by means of the over-current reducing arrangement may flow into the protected object. For this purpose the device comprises a further breaker arranged in the line between the circuit breaker and the object, said further breaker being designed to break at a lower voltage and current than the switching device and therefore may be designed with a shorter break-time than the switching device as a consequence of a smaller need for movement and a smaller weight of the movable contact(s) of the breaker, said further breaker being arranged to break not until a time when the over-current towards or away from the protected object has been reduced by means of the over-current reducing arrangement. More specifically, the movement required of the movable contact(s) of the further breaker is smaller due to lower voltage whereas the weight of the contact(s) may be held lower due to the fact that the lower current does not require such large contact areas.

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As is more closely defined in the claims, the invention is applicable on transformers and reactors constructed by means of unconventional technique, namely cable technology. These may under certain conditions become sensitive to electric faults. Such a design may for instance be given a lower impedance than what is considered conventional today within the power field. This means that the design does not have the same resistance against fault-related overcurrents, internal as well as external, as the conventional apparatus of today. If the apparatus, besides, has been designed from the start to operate with a higher electrical voltage than the conventional apparatus of today, the strain on the electrical insulation system of the apparatus, caused by the resulting higher electrical field, becomes, of course, greater. This means that the apparatus may be more efficient, more economical, mechanically lighter, more reliable, less expensive to produce and generally more economical than conventional apparatus and may manage without the usual connection to other electromagnetic apparatus, such an apparatus requires an adequate electric protection to eliminate, or at least reduce, the consequences of a breakdown in the apparatus in question. A combination of the protection device according to the invention and an apparatus designed in this way, preferably a transformer or reactor, means an optimization of the plant in its entirety.

The non-conventional transformer intended here is a power transformer with a rated power of from a few hundred kVA up to over 1000 MVA with a rated voltage of from 3-4 kV up to very high transmission voltages, such as 400 kV to 800 kV or higher, and which does not entail the disadvantages, problems and limitations which are associated with the prior art oil-filled power transformer according to what appears above.

The invention is based on the realization that by designing at least one winding in the transformer/reactor such that it comprises a solid insulation surrounded by an outer and an inner potential-equalizing semiconducting layer, within which inner layer the at least one electric conductor is disposed, a possibility is provided of maintaining the electric field in the whole plant within the conductor. The electric conductor is, according to the invention, suitably so arranged that it has such conducting contact with the inner semiconducting layer that no harmful potential differences may arise in the boundary layer between the innermost part of the solid insulation and the semiconducting layer located inwardly thereof. Such a power transformer exhibits great advantages relative to a conventional oil-filled transformer. As mentioned by way of introduction, the invention also provides for the concept to be applied to reactors both with and without a core of magnetic material.

The essential difference between conventional oil-filled power transformers/reactors and a power transformer/reactor according to the invention is that the winding/windings thus comprise a solid insulation surrounded by external and internal potential layers as well as at least one electric conductor arranged inwardly of the inner potential layer, said potential layers being made from a semiconducting material. The definition of what is comprised by the concept semiconductor will be described below. According to a preferred embodiment, the winding/windings is/are designed in the form of a flexible cable.

At the high voltage levels which are required in a power transformer/reactor according to the invention, which is connected to high-voltage networks with very high operat-

ing voltages, the electric and thermal loads which may arise will impose extreme demands on the insulating material. It is known that so called partial discharges, pd, generally constitute a serious problem for the insulating material in high-voltage installations. If cavities, pores or the like arise at an insulating layer, internal corona discharges may arise at high electric voltages, whereby the insulating material is gradually degraded, which finally may lead to electric break-down through the insulation. It is realized that this can lead to serious break-down of, for example, a power transformer.

The invention is, inter alia, based on the realization that it is of extreme importance that the semiconducting potential layers exhibit similar thermal properties and that the layers are firmly connected to the solid insulation. The thermal properties in view here relate to coefficient of thermal expansion. The inner and outer semiconducting layers and the intermediate insulation should, accordingly, be well integrated, i.e. in good contact with each other over substantially the entire boundary layer, independently of the temperature changes occurring at different loads. Thus, the insulation including the surrounding semiconducting layers will, at temperature gradients, constitute a monolithic part and defects caused by different temperature expansion in the insulation and the surrounding layers do not arise. The electric load on the material is reduced as a consequence of the fact that the semiconducting layers around the insulation will constitute equipotential surfaces and that the electric field in the insulation will hence be distributed uniformly over the insulation.

According to the invention, it must be ensured that the insulation is not broken down by the phenomena described above. This can be achieved by using as insulation system

semiconducting layers and intermediate insulation layer produced in such a way that the risk for cavities and pores is minimal, for example extruded layers of a suitable plastic material, such as XLPE (cross linked polyethylene) and EP-rubber (EP = ethylene-propylene). The insulating material is thus a low-loss material with high break-down strength.

It is known that transmission cables for high voltage are designed with conductors having an extruded insulation with an inner and outer semiconducting layer. In transmission of electrical energy, one has since long ago aimed at avoiding defects in the insulation. However, in high voltage transmission cables the electric potential along the length of the cable is not changed, but the potential lies, in principle, at the same level, which means a high electric stress on the insulating material. The transmission cable is provided with one inner and one outer semiconducting layer for potential equalization.

Thus, the winding is according to the invention provided with a solid insulation and surrounding potential equalizing layers, whereby the transformer/reactor may be obtained, in which the electrical field is retained within the winding. Additional improvements may also be achieved by constructing the conductor from smaller insulated parts, so-called strands. By making these strands small and circular, the magnetic field across the strands will exhibit constant geometry in relation to the field and the occurrence of eddy currents is minimized.

According to the invention the winding/windings is/are thus preferably made in the form of a cable comprising at least one conductor comprising a number of strands

and an inner semiconducting layer around the strands. Outside of this inner semiconducting layer is the main insulation of the cable in the form of a solid extruded insulation, and around this insulation there is an outer
5 semiconducting layer. The cable may in certain connections have additional outer and inner layers. For instance, further potential equalizing, semiconducting layers could be arranged in the solid insulation between those two layers which in this specification are denomi-
10 nated "inner" and "outer" In such a case, this additional layer will lie on a medium potential.

According to the invention, the outer semiconducting layer shall exhibit such electrical properties that a
15 potential equalization along the conductor is ensured. The semiconducting layer may, however, not exhibit such conductivity properties that a current will be induced in the layer, said current causing an unwanted thermal load. However, the conducting properties of the layer
20 must be sufficient to ensure that the outer layer is capable of forming an equipotential surface. The inner semiconducting layer must present a sufficient electrical conductivity to be able to operate potential-equalizing and, accordingly, equalizing with regard to the
25 electrical field outside the inner layer. In this connection it is important that the layer has such properties that it equalizes irregularities in the surface of the conductor and so that the layer is capable of forming an equipotential surface with a high surface finish
30 at the border layer to the rigid insulation. The inner layer may be formed with a varying thickness but in order to ensure an even surface with respect to the conductor and the solid insulation, the thickness of the layer should be between 0,5 and 1 mm. However, the inner
35 layer may not exhibit such a high electrical conduction

capacity that the layer contributes to induction of voltages.

5 The resistivity for the inner and outer layers should lie in the range $10^{-6} \Omega\text{cm}$ - $100 \text{ k}\Omega\text{cm}$, suitably 10^{-3} - $1000 \Omega\text{cm}$, preferably $1\text{-}500 \Omega\text{cm}$. Furthermore, it is preferred that the inner and outer layers each exhibit a resistance, which per meter cable is in the range $50 \mu\Omega$ - $5 \text{ M}\Omega$.

10

Thus, such a XLPE cable or a cable with EP rubber insulation or a corresponding cable is used according to the invention in a modified embodiment and in an entirely new field of use as winding in a magnetic circuit.

15

A winding comprising such a cable will entail quite different conditions from the insulation point of view from those which apply to conventional transformers/reactor windings due to the electric field distribution. To
20 utilize the advantages afforded by the use of the mentioned cable, there are other possible embodiment as regards grounding of a transformer/reactor according to the invention than that which is applicable for conventional oil-filled power transformers. These methods are
25 the subject matter of separate application for patent.

It is essential and necessary for a winding in a power transformer/reactor according to the invention that at least one of the strands of the conductor is uninsulated
30 and arranged such that good electrical contact is achieved with the inner semiconducting layer. Thus, the inner layer will always lie on the potential of the conductor.

As far the rest of the strands are concerned, all of them or some of them may be insulated, for example by being varnished.

5 Manufacturing transformer or reactor windings of a cable according to the above entails drastic differences as regards the electrical field distribution between conventional power transformers/reactors and a power transformer/reactor according to the invention. The decisive
10 advantage with a cable-formed winding according to the invention is that the electric field is enclosed in the winding and that there is, thus, no electric field outside the outer semiconducting layer. The electric field achieved by the current-carrying conductor occurs in essential only in the solid main insulation. Both from the
15 design point of view and the manufacturing point of view this means considerable advantages;

- The windings of the transformer may be formed without
20 having to consider any electric field distribution and the transposition of strands, mentioned under the background art is omitted.

- The core design of the transformer may be formed without
25 having to consider any electric field distribution.

- No oil is needed for electrical insulation of the winding, that is, the medium surround the winding may be
30 air.

- No special connections are required for electrical connection between the outer connections of the transformer and the immediately connected coils/windings since the electrical connection, contrary to conventional plants, is integrated with the winding.
35

- The manufacturing and testing technology which is needed for a power transformer according to the invention is considerably simpler than for a conventional power transformer/reactor since the impregnation, drying and vacuum treatments described under the description of the background art are not needed.

Further advantages and features of the invention, in particular with respect to the method according to the invention, appear from the following description and the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

With reference to the enclosed drawings, a more specific description of an embodiment example of the invention follows hereinafter.

In the drawings:

Fig 1 is a purely diagrammatical view illustrating the basic aspects behind the solution according to the invention,

Figs 2-2d are diagrams illustrating in a diagrammatical form and in a comparative way fault current developments and the energy development with and without the protection device according to the invention;

Fig 3 is a diagrammatical view illustrating a conceivable design of a device according to the invention;

- Fig 4 is a diagrammatical view illustrating a possible design of the over-current reducing arrangement;
- Fig 5 is a diagrammatical view illustrating the device according to the invention applied in an electrical power plant comprising a generator, a transformer and a power network connected thereto;
- Fig 6 shows the electric field distribution about a winding of a conventional power transformer/reactor;
- Fig 7 shows an example of a cable used in the windings of the power transformers/reactors according to the invention, and
- Fig 8 illustrates an embodiment of a power transformer according to the invention.

20 DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

An electric power plant comprising a protected object 1 is shown in Fig 1. As is described hereunder, this object could for instance consist of a transformer or reactor.

This object is connected, via a line 2, to an external distribution network 3. Instead of such a network, the unit denoted 3 could be formed by some other equipment contained in the power plant. The power plant involved is conceived to be of such a nature that it is the object 1 itself which primarily is intended to be protected against fault currents from the network/equipment 3 when there occurs a fault in the object 1 giving rise to a fault current from the network/equipment 3 towards the object 1 so that the fault current will flow through the object.

Said fault may consist in a short-circuit having been formed in the object 1. A short-circuit is a conduction

path, which is not intended, between two or more points. The short-circuit may for instance consist of an arc. This short-circuit and the resulting violent current flow may involve considerable damage and even a total break-down of the object 1.

It is already pointed out that with at least some types of protected electrical objects 1, short-circuit currents/fault currents harmful to the object in question may flow from the protected object towards the network/equipment 3. Within the scope of the invention, it is intended to be used for protection purposes not only for protection of the object from externally emanating fault currents flowing towards the object but also from internal fault currents in the object flowing in the opposite direction. This will be discussed in more detail in the following.

In the following, the designation 3 will, to simplify the description, always be mentioned as consisting of an external power network. However, it should be kept in mind that some other equipment may be involved instead of such a network, as long as said equipment causes violent current flow through the object 1 when there is a fault.

A conventional circuit breaker 4 is arranged in the line 2 between the object 1 and the network 3. This circuit breaker comprises at least one own sensor for sensing circumstances indicative of the fact that there is an overcurrent flowing in the line 2. Such circumstances may be currents/voltages but also other indicating that a fault is at hand. For instance, the sensor may be an arc sensor or a sensor recording short circuit sound etc. When the sensor indicates that the overcurrent is above a certain level, the circuit breaker 4 is activated for breaking of the connection between the object 1 and the network

3. The circuit breaker 4 must, however, break the total short circuit current/fault current. Thus, the circuit breaker must be designed to fulfil highly placed requirements, which in practice means that it will operate relatively slowly. In Fig 2a it is illustrated in a current/time-diagram that when a fault, for instance a short circuit in the object 1, occurs at the time t_{fault} , the fault current in the line denoted 2 in Fig 1 rapidly assumes the magnitude i_1 . This fault current i_1 is broken by means of the circuit breaker 4 at t_1 , which is at least within 150 ms after t_{fault} . Fig 2d illustrates the diagram $i^2 \cdot t$ and, accordingly, the energy developed in the protected object 1 as a consequence of the short circuit therein. The energy injection into the object occurring as a consequence of the short-circuit current is, accordingly, represented by the total area of the outer rectangle in Fig 2d.

It is in this connection pointed out that the fault current in Figs 2a-c and the currents in Fig 2d represent the envelope of the extreme value. Only one polarity has been drawn out in the diagram for the sake of simplicity.

The circuit breaker 4 is of such a design that it establishes galvanic separation by separation of metallic contacts. Accordingly, the circuit breaker 4 comprises, as a rule, required auxiliary equipment for arc extinguishing.

According to the invention the line 2 between the object 1 and the switching device 4 is connected to an arrangement reducing overcurrents towards the apparatus 1 and generally denoted 5. The arrangement is actuatable for overcurrent reduction with the assistance of an overcurrent conditions detecting arrangement within a time period substantially less than the break time of the circuit breaker 4. This arrangement 5 is, accordingly, designed such that

it does not have to establish any galvanic separation. Therefore, conditions are created to very rapidly establish a current reduction without having to accomplish any total elimination of the current flowing from the network 3 towards the protected object 1. Fig 2b illustrates in contrast to the case according to Fig 2a that the overcurrent reducing arrangement 5 according to the invention is activated upon occurrence of a short circuit current at the time t_{fault} for overcurrent reduction to the level i_2 at the time t_2 . The time interval $t_{\text{fault}} - t_2$ represents, accordingly, the reaction time of the overcurrent reducing arrangement 5. By the task of the arrangement 5 not to break but only reduce the fault current, the arrangement may be caused to react extremely rapidly, which will be discussed more closely hereunder. As an example, it may be mentioned that current reduction from the level i_1 to the level i_2 is intended to be accomplished within one or a few ms after unacceptable overcurrent conditions having been detected. It is then aimed at to accomplish the current reduction in a shorter time than 1 ms, and preferably more rapidly than 1 microsecond.

As appears from Fig 1, the device comprises a further breaker generally denoted 6 and arranged in the line 2 between the circuit breaker 4 and the object 1. This further breaker is designed to break a lower voltage and currents than the circuit breaker 4 and may, as a consequence thereof, be designed to operate with shorter break times than the circuit breaker. The further breaker 6 is arranged to break not until after the overcurrent from the network 3 towards the object 1 has been reduced by means of the overcurrent reducing arrangement 5 but substantially earlier than the circuit breaker 4. From that stated, it appears that the further breaker 6 should be coupled to the line 2 in such a way that it is the current reduced by means of the overcurrent reducing arrangement 5

which will flow through the further breaker and which, accordingly, is to be broken by means thereof.

Fig 2b illustrates the action of the further breaker 6. This breaker is, more specifically, designed to break at the time t_3 , which means that the duration of the current i_2 reduced by means of the overcurrent reducing arrangement 5 is substantially delimited, namely to the time period t_2 - t_3 . The consequence is that the energy injection into the protected object 1 caused by a fault current from the network 3 is represented by the surfaces marked with oblique lines in Fig 2d. It appears that a drastic reduction of the energy injection is achieved. In this connection it is pointed out that since, according to a specific model, the energy increases with the square of the current, a reduction to one half of the current reduces the energy injection to a fourth. It is illustrated in Fig 2c how the fault current will flow through the arrangement 5.

The dimensioning of the arrangement 5 and the further breaker 6 is conceived to be carried out such that the arrangement 5 reduces the fault current and the voltage to be broken by means of the further breaker 6 to substantially lower levels. A realistic break time as to the further breaker 6 is 1 ms. However, the dimensioning should be made such that the breaker 6 is caused to break not until after the arrangement 5 having reduced the current flowing through the breaker 6 to at least a substantial degree.

It is illustrated in more detail in Fig 3 how the device may be realised. It is then pointed out that the invention is applicable in direct current (also HVDC = High Voltage Direct Current) and alternating-current connections. In the latter case, the line denoted 2 may be considered to

form one of the phases in a multiphase alternating-current system. However, it should be kept in mind that the device according to the invention may be realised so that either all phases are subjected to the protection function according to the invention in case of a detected fault or that only that phase or those phases where a fault current occurs which are subjected to current reduction.

It appears from Fig 3 that the overcurrent reducing arrangement generally denoted 5 comprises an overcurrent diverter 7 for diverting overcurrents to earth 8 or otherwise another unit having a lower potential than the network 3. Thus, the overcurrent diverter may be considered as forming a current divider which rapidly establishes a short circuit to earth or otherwise a low potential 8 for the purpose of diverting at least a substantial part of the current flowing in the line 2 so that said current does not reach the object 1 to be protected. If there is a serious fault in the object 1, for instance a short circuit, which is of the same magnitude as the short circuit that the overcurrent diverter 7 is capable of establishing, it may be said that generally speaking a reduction to one half of the current flowing to the object 1 from the network 3 is achieved as a consequence of the overcurrent diverter 7 in case the fault is close to the latter. In comparison with Fig 2b, it appears, accordingly, that the current level i_2 illustrated therein and being indicated to amount to approximatively half of i_1 may be said to represent the worst occurring case. Under normal conditions, the purpose is that the overcurrent diverter 7 should be able to establish a short circuit having a better conductivity than the one corresponding to the short circuit fault in the object 1 to be protected so that accordingly a main part of the fault current is diverted to earth or otherwise a lower potential via the overcurrent diverter 7. It appears from this that, accord-

ingly, in a normal fault case, the energy injection into the object 1 in case of a fault becomes substantially smaller than that which is indicated in Fig 2d as a consequence of lower current level i_2 as well as shorter time span t_2-t_3 .

The overcurrent diverter 7 comprises switch means coupled between earth 8 or said lower potential and the line 2 between the object 1 and the network 3. This switch means comprises a control member 9 and a switch member 10. This switch member may for instance be formed by at least one semiconductor component, for instance a thyristor, which is open in a normal state, i.e. isolating in relation to earth, but via the control member 9 may be brought into an active, conducting state in a very short time in order to establish current reduction by diversion to earth.

Fig 3 illustrates that an overcurrent conditions detecting arrangement may comprise at least one and preferably several sensors 11-13 suitable for detecting such overcurrent situations requiring activation of the protection function. As also appears from Fig 3, these sensors may include the sensor denoted 13 located in the object 1 or in its vicinity. Furthermore, the detector arrangement comprises a sensor 11 adapted to sense overcurrent conditions in the line 2 upstreams of the connection of the overcurrent reducing arrangement 5 and the line 2. As is also explained in the following, it is suitable that a further sensor 12 is provided to sense the current flowing in the line 2 towards the object 1 to be protected, i.e. the current which has been reduced by means of the overcurrent reducing arrangement 5. In addition, it is pointed out that the sensor 12, as well as possibly the sensor 13, is capable of sensing the current flowing in the line 2 in a direction away from the object 1, for instance in cases

where energy magnetically stored in the object 1 gives rise to a current directed away from the object 1.

It is pointed out that the sensors 11-13 do not necessarily have to be constituted by only current and/or voltage sensing sensors. Within the scope of the invention, the sensors may be of such nature that they generally speaking may sense any conditions indicative of the occurrence of a fault of the nature requiring initiation of a protection function.

In cases where such a fault occurs that the fault current will flow in a direction away from the object 1, the device is designed such that the control unit 14 thereof will control the further breaker 6 to closing, in case it would have been open, and, in addition, the overcurrent reducing arrangement 5 is activated such that the short circuit current may be diverted by means of the same.

When, for example, the object 1 is conceived to consist of a transformer, the function on occurrence of a short circuit therein could be such that the short circuit first gives rise to a violent flow of current into the transformer, which is detected and gives rise to activation of the arrangement 5 for the purpose of current diversion. When the current flowing towards the transformer 1 has been reduced in a required degree, the breaker 6 is caused to break, but, controlled by means of the control unit 14, not earlier than leaving time for the energy, in occurring cases, magnetically stored in the transformer 1 to flow away from the transformer 1 and be diverted via the arrangement 5.

Furthermore, the device comprises a control unit generally denoted 14. This is connected to the sensors 11-13, to the overcurrent reducing arrangement 5 and to the further

breaker 6. The operation is such that when the control unit 14 via one or more of the sensors 11-13 receives signals indicating occurrence of unacceptable fault currents towards the object 1, the overcurrent reducing arrangement 5 is immediately controlled to rapidly provide the required current reduction. The control unit 14 may be arranged such that when the sensor 12 has sensed that the current or voltage has been reduced to a sufficient degree, it controls the breaker 6 to obtain operation thereof for breaking when the overcurrent is below a predetermined level. Such a design ensures that the breaker 6 is not caused to break until the current really has been reduced to such a degree that the breaker 6 is not given the task to break such a high current that it is not adequately dimensioned for that purpose. However, the embodiment may alternatively also be such that the breaker 6 is controlled to break a certain predetermined time after the overcurrent reducing arrangement having been controlled to carry out current reduction.

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The circuit breaker 4 may comprise a detector arrangement of its own for detection of overcurrent situations or otherwise the circuit breaker may be controlled via the control unit 14 based upon information from the same sensors 11-13 also controlling the operation of the overcurrent reducing arrangement.

25

It is illustrated in Fig 3 that the further breaker 6 comprises a switch 15 having metallic contacts. This switch 15 is operable between breaking and closing positions by means of an operating member 16, which in turn is controlled by the control unit 14. A shunt line 17 is connected in parallel over this switch 15, said shunt line comprising one or more components 18 intended to avoid arcs on separation of the contacts of the switch 15 by causing the shunt line 17 to take over the current

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conduction from the contacts. These components are designed so that they may break or restrict the current. Thus, the purpose is that the components 18 normally should keep the conduction path in the shunt line 17 interrupted but close the shunt line when the switch 15 is to be opened so that accordingly the current is shunted past the switch 15 and in that way arcs do not occur or possibly occurring arcs are efficiently extinguished. The components 18 comprise one or more associated control members 19 connected to the control unit 14 for control purposes. According to one embodiment of the invention, said components 18 are controllable semiconductor components, for instance GTO thyristors, having necessary surge arresters 30.

A disconnecter 20 for galvanic separation in the current conduction path created by means of the shunt line 17 to the object 1 to be protected is arranged in series with said one or more components 18. This disconnecter 20 is via an operating member 21 controlled by the control unit 14. The disconnecter 20 is illustrated in Fig 3 as being placed in the shunt line 17 itself. This is of course not necessary. The disconnecter 20 could also be placed in the line 2 as long as it ensures real galvanic separation, by series coupling with said one or more components 18, in the conduction path established by means of said series coupling so that accordingly there is not any possibility for current to flow through the components 18.

The device as it has been described so far operates in the following manner: In absence of a fault, the circuit breaker 4 is closed just like the switch 15 of the further breaker 6. The components 18 in the shunt line 17 are in a non-conducting state. The disconnecter 20 is closed. Finally, the switch means 10 of the overcurrent reducing arrangement 5 is open, i.e. it is in a non-conducting

state. In this situation the switch means 10 must, of course, have an adequate electrical strength so that it is not inadvertently brought into a conducting state. Over-voltage conditions occurring in the line 2 as a consequence of atmospheric (lightning stroke) circumstances or coupling measures may, accordingly, not involve the voltage strength of the switch means 10 in its non-conducting state to be exceeded. For this purpose it is suitable to couple at least one surge arrester 22 in parallel with the switch means 10. In the example such surge arresters are illustrated on both sides of the switch means 10. Accordingly, the surge arresters have the purpose to divert such overvoltages which otherwise could involve a risk for inadvertent breakthrough in the switch means 10.

When an over-current state has been registered by means of some of the sensors 11-13 or the own sensor (it is of course realized that information from the own sensor of the circuit breaker 4 may be used as a basis for control of the over-current reducing arrangement 5 according to the invention) of the circuit breaker 4 and this over-current state is of such magnitude that a serious fault of the object 1 is expected to be at hand, a breaking operation is initiated as far as the circuit breaker 4 is concerned. In addition, the control unit 14 controls the over-current reducing arrangement 5 to effect such reduction, and this more specifically by bringing, via the control member 9, the switch means 10 into an electrically conducting state. As described before, this may occur very rapidly, i.e. in a fraction of the time required for breaking by means of the circuit breaker 4, for what reason the object 1 to be protected immediately is liberated from the full short-circuit current from the network 3 as a consequence of the switch means 10 diverting at least an essential part, and in practice the main part, of the current to earth or otherwise a lower potential. As soon

as the current, which flows towards the object 1 via the further breaker 6, has been reduced in a required degree, which can be established on a pure time basis by a time difference between activation of the switch means 10 and operation of the breaker 6, or by sensing of the current flowing in the line 2 by means of, for instance, the sensor 12, the operating member 16 of the switch 15 is, via the control unit 14, controlled to open the contacts of the switch 15. For extinguishing or avoiding arcs, the components 18, e.g. GTO thyristors or gas switches, are via the control members 19 controlled to establish conductivity of the shunt line 17. When the switch 15 has been opened and, thus, provided galvanic separation, the component 18 is again controlled to bring the shunt line 17 into a non-conducting state. In that way the current from the network 3 towards the object 1 has been efficiently cut off. After having brought the shunt line 17 into a non-conducting state, galvanic separation may, in addition, be effected by means of the disconnecter 20 by controlling the operating member 21 thereof from the control unit 14. When all these incidents have occurred, breaking by means of the circuit breaker 4 occurs as a last incident. It is important to note that the over-current reducing arrangement as well as the further breaker 6 according to a first embodiment can be operated repeatedly. Thus, when it has been established by means of the sensors 11-13 that the circuit breaker 4 has been brought to cut off, the switch means 10 is reset to a non-conducting state and the switch 15 and the disconnecter 20 are again closed so that when the circuit breaker 4 next time closes, the protection device is completely operable. According to another embodiment, it is, however, contemplated that the over-current reducing arrangement 5 may require exchange of one or more parts in order to operate again.

It is pointed out that according to an alternative embodiment of the invention, the component or components 18 could be brought into a conducting state as soon as the over-current reducing arrangement 5 has been brought into a closing state and this independently of whether the switch 15 possibly is not opened thereafter. The control of the components 18 could then, as described before, occur via the control unit 14 or, alternatively, by means of a control function involving a slavish following of the closing of the arrangement 5.

Fig 4 illustrates an alternative embodiment of the over-current reducing arrangement 5. Instead of relying on a semiconductor switch means as in Fig 3, the embodiment according to Fig 4 is intended to involve causing of a medium present in a gap 24 between electrodes 23 to assume electrical conductivity by means of a control member 9a. This control member is arranged to control the operation of members 25 for causing or at least initiating the medium or a part thereof in the gap 24 into a conducting state. Said member 25 is in the example arranged to cause the medium in the gap 24 to assume electrical conductivity by causing or at least assisting in causing the medium to ionization/plasma. It is preferred that the members 25 comprise at least one laser, which by energy supply to the medium in the gap 24 provides for the ionization. As appears from Fig 4, a mirror 26 may be used for necessary diverting of the laser beam bundle. It is in this connection pointed out that the embodiment according to Fig 4 may be such that the means 25 do not alone give rise to ionization/plasma in the entire electrode gap. Thus, the intention may be that an electrical field imposed over the gap should contribute in ionization/plasma formation, only a part of the medium in the gap being ionized by means of the members 25 so that thereafter the electrical field in the gap gives rise to establishment of plasma in

the entire gap. It is in this connection pointed out that there may be in the electrode gap not only a medium consisting of various gases or gas mixtures but also vacuum. In the case of vacuum, initiation by means of
5 laser occurs at at least one of the electrodes, which, accordingly, will function as an electrone and ion transmitter for establishment of an ionized environment/a plasma in the electrode gap.

10 Fig 5 illustrates a conventional embodiment in the sense that a generator 1b via a transformer 1a is coupled to a power network 3a. The objects to be protected are, accordingly, represented by the transformer 1a and the generator 1b. The over-current reducing arrangement 5a and the fur-
15 ther breaker 6a and the ordinary circuit breaker 4a are, as can be seen, arranged similar to what appears from Fig 1 for the case that the object 1 shown therein is conceived to form the object 1a according to Fig 5. Accordingly, reference is in this regard made to the descrip-
20 tions delivered with respect to Fig 1. The same is due for the protection function of the over-current reducing arrangement 5c and the further breaker 6c with respect to the generator 1b. In this case, the transformer 1a could, accordingly, be considered equivalent with the object 1 in
25 Fig 1 whereas the generator 1b could be considered equivalent to the equipment 3 in Fig 1. Thus, the over-current reducing arrangement 5c and the further breaker 6c will, in combination with the conventional circuit breaker 4b, be able to protect the transformer 1 against violent flow
30 of current in a direction away from the generator 1b.

As an additional aspect in Fig 5, the additional over-current reducing arrangement 5b with associated further breakers 6b are present. As can be seen, there will be
35 over-current reducing arrangements 5a and 5b on either side of the transformer 1a. It is then pointed out that

the further breakers 6a and 6b respectively are arranged in the connections between said over-current reducing arrangements 5a and 5b and the transformer 1a. The further over-current reducing arrangement 5b is intended to protect the transformer 1a from current flows towards the transformer from the generator 1b. As can be seen, the circuit breaker 4b will be able to break independently of in which direction between the objects 1a and 1b a protection function is desired.

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With the assistance of Figs 6-8 an embodiment according to the invention in the form of a non-conventional design of a transformer/reactor will now be described.

15 Fig 7 shows an example of a cable which may be used in the windings which are included in dry power transformers reactors according to the invention. Such a cable comprises at least one conductor 30 consisting of a number of strands 31 with an inner semiconducting layer 32 arranged
20 around the strands. Outside this inner semiconducting layer is the main insulation 33 of the cable in the form of a solid, suitably extruded insulation and surrounding this solid extruded insulation an outer semiconducting layer 34. The cable may, as mentioned previously, be provided with other additional layers for special purposes,
25 for example for preventing too high electric stresses on other regions of the transformer/reactor. From the point of view of geometrical dimensions, the cables in question will have a conductor area which is between 80 and 3000
30 mm² and an outer cable diameter which is between 20 and 250 mm.

The windings of a power transformer/reactor manufactured from the cable described above may be used both for single
35 phase, three phase and poly phase transformers/reactors independently of how the core is shaped. One embodiment is

shown in Fig 8, which illustrates a three phase laminated core transformer. The core comprises, in conventional manner, three core limbs 35, 36 and 37 and the retaining yokes 38 and 39. In the embodiment shown, both the core limbs and the yokes have a tapering cross section.

Concentrically around the core limbs, the windings formed with the cable are located. The embodiment shown in Fig 8 has, as can be seen, three concentric winding turns 40, 41 and 42. The innermost winding turn 40 may represent the primary winding and the other two winding turns 41 and 42 may represent secondary windings. In order not to overload the figure with too many details, the connections of the windings are not shown. Otherwise the Figure shows that, in the embodiment shown, spacing bars 43 and 44 with several different functions are disposed at certain points around the windings. The spacing bars may be formed of insulating material intended to provide a certain space between the concentric winding turns for cooling, bracing etc. They may also be formed of electrically conducting material in order to form part of the grounding system of the windings.

It should be noted that the description presented hereinabove only should be considered as exemplifying for the inventive idea, on which the invention is built. Thus, it is obvious for the man skilled in the art that detail modifications may be made without leaving the scope of the invention. As an example, it may be mentioned that it would be possible to use as a switch means 10 a mechanical switch.

Claims

1. A device in an electric power plant for protection of an object (1) connected to an electric power network (3) or another equipment included in the electric power plant from fault-related over-currents, the device comprising a switching device (4) in a line (2) between the object and the network/equipment, characterized in that the line (2) between the object and the switching device is connected to an over-current reducing arrangement (5), which is actuatable for over-current reduction with assistance of an over-current conditions detecting arrangement (11-13) within a time period substantially shorter than the break-time of the switching device.
2. A device according to claim 1, characterized in that the switching device (4) is formed by a circuit-breaker.
3. A device according to claim 1 or 2, characterized in that the over-current reducing arrangement (5) comprises an over-current diverter (7) for diverting over-currents to earth (8) or otherwise another unit having a lower potential than the network/equipment.
4. A device according to claim 3, characterized in that the over-current diverter (7) comprises a switch means (10) coupled between earth or said lower potential and the line between the object (1) and the network/equipment (3).
5. A device according to claim 4, characterized in that the switch (10) comprises at least one semiconductor component.
6. A device according to claim 4, characterized in that the switch (10a) comprises an electrode gap (24) and means (25) for causing or at least initiating the electrode gap

or at least a part thereof to assume electrical conductivity.

5 7. A device according to claim 6, characterized by said means (25) for causing or at least initiating the electrode gap to assume electrical conductivity being arranged to cause the gap or a part thereof to assume the form of a plasma.

10 8. A device according to claim 7, characterized by said members (25) for causing or at least initiating the electrode gap or a part thereof to assume electrical conductivity comprising at least one laser.

15 9. A device according to any preceding claim, characterized in that it comprises a further breaker (6) arranged in the line between the switching device (4) and the object, said further breaker being arranged between the over-current reducing arrangement (5) and the object (1) and being adapted to break lower voltages and currents
20 than the switching device (4) and therefore capable of performing a shorter break-time than the switching device, and that the further breaker is adapted to break when the over-current towards or away from the object (1) has been
25 reduced by means of the over-current reducing arrangement (5) but substantially earlier than the switching device.

30 10. A device according to claim 9, characterized in that it comprises a control unit (14) connected to the detecting arrangement (11-13) and to the further breaker (6) in order to achieve actuation of the further breaker for breaking purposes when the over-current towards or away from the object (1) is indicated, by means of the detecting arrangement, to be under a predetermined level.

11. A device according to any of claims 9-10, characterized in that the further breaker (6) comprises a switch (15), over which there is coupled a shunt line (17) having one or more components (18) for avoiding arcs on separation of contacts of the switch (15) by causing the shunt line (17) to take over current conduction from the contacts.

12. A device according to claim 11, characterized in that said one or more components in the shunt line (17) are closable into conduction by means of control via the control unit (14).

13. A device according to claim 11 or 12, characterized in that said one or more components (18) are formed by controllable semiconductor components.

14. A device according to any of claims 11-13, characterized in that said one or more components (18) are provided with at least one surge arrester (30).

15. A device according to any of claims 11-14, characterized in that a disconnecter (20) for galvanic separation is arranged in series with said one or more components (18).

16. A device according to claim 15, characterized in that the disconnecter (20) is coupled to the control unit (14) to be controlled thereof for opening after the switch (15) having been controlled to have closed and said one or more components (18) having been placed in a condition for breaking the shunt line (17).

17. A device according any preceding claim, characterized in that at least one search arrester (22) is coupled in parallel with the over-current reducing arrangement (5).

18. A device according to any preceding claim, characterized in that two over-current reducing arrangements are arranged on either sides of the object to protect the same
5 from two sides.

19. A device according to claim 1, characterized in that it comprises a control unit (14) connected to the over-current reducing arrangement (5) and to the over-current
10 conditions detecting arrangement (11-13), said control unit (14) being arranged to control the over-current reducing arrangement to closing based upon information from the over-current conditions detecting arrangement when required for reasons of protection.

15

20. A device according to claim 19 and one or more of the claims 10, 12 and 16, characterized in that one and the same control unit (14) is arranged to control, based upon information from the over-current conditions detecting
20 arrangement (11-13), the over-current reducing arrangement (5) and the further breaker (6).

21. A device according to any preceding claim, characterized in that the protected object (1) is formed by an
25 electric apparatus with a magnetic circuit.

22. A device according to claim 21, characterized in that the object is formed by a transformer or reactor.

30 23. A device according to any of claims 21-22, characterized in that the electric apparatus provided with magnetic circuit is designed for high voltage, suitably 72.5 kV and more.

35 24. A device according to any of claims 23-24, characterized in that the magnetic circuit of the electric

apparatus comprises a winding formed by means of a cable.

25. A device according to any of claims 21-24, characterized in that at least one winding of the apparatus comprises at least one conductor (30) and around this conductor an electric insulation (33) of a solid insulation material, that an outer layer (34) of a semiconducting material is arranged around the insulation, that an inner layer (32) of a semiconducting material is arranged inwardly of the insulation (33) and that said at least one conductor (30) is arranged inwardly of the inner layer (32).
26. A device according to claim 25, characterized in that at least one of the inner and outer layers (32, 34) have substantially equal thermal coefficient of expansion as the insulation material.
27. A device according to any of claims 25 and 26, characterized in that the inner layer (32) is in electric contact with said at least one conductor (30).
28. A device according to any of claims 25-27, characterized in that the outer layer (34) essentially forms an equipotential surface.
29. A device according to any of claims 25-28, characterized in that the inner and outer semiconducting layers (32, 34) and the insulation (33) are bonded to each other over substantially the entire interface.
30. A device according to claim 25, characterized in that at least one of the strands (31) of the conductor (30) is uninsulated and arranged such that electrical contact is achieved with the inner semiconducting layer (32).

31. A device according to any of claims 25-30, characterized in that the cables are manufactured with a conductor area which is between 80 and 3000 mm² and with an
5 outer cable diameter which is between 20 and 250 mm.

32. A device according to any of claims 22-31, characterized in that the object designed as a power transformer/reactor comprises a core formed by magnetic material and consisting of core limbs and yokes.
10

33. A device according to any of claims 21-32, characterized in that the power transformer/reactor is formed without a core (air-wound).
15

34. A device according to any of claims 21-33, comprising at least two galvanically separated windings, characterized in that the windings are concentrically wound.

20 35. Use of a device according to any preceding claim for protection of an object in the form of a transformer or reactor against fault-related overcurrents.

36. A method in an electric power plant for protection
25 of an object (1) connected to an electric power network (3) or another equipment contained in the electric power plant from fault-related overcurrents, a switching device (4) being located in a line between the object and the network/equipment, characterized in that an overcurrent reducing arrangement (5) connected to the line
30 between the object (1) and the switching device (4) is activated for overcurrent reduction when overcurrent conditions have been detected by means of an arrangement (11-13) for this purpose, within a time period substantially shorter than the break time of the switching
35 vice (4).

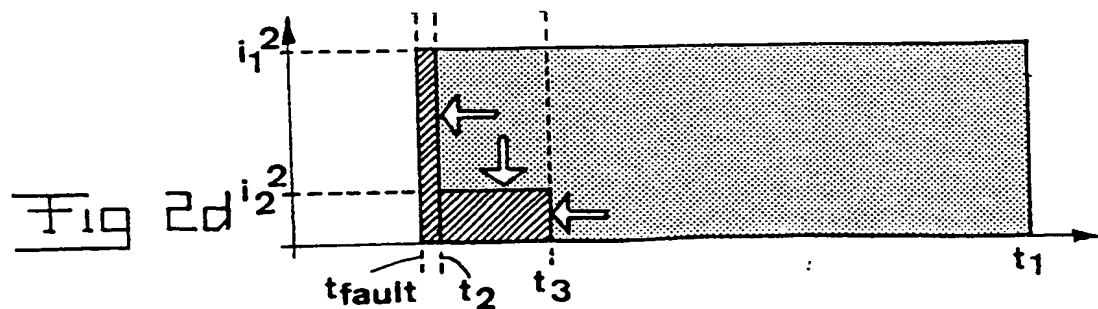
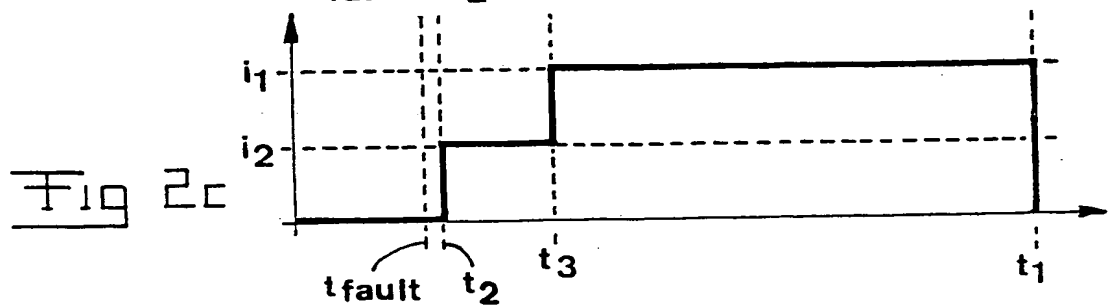
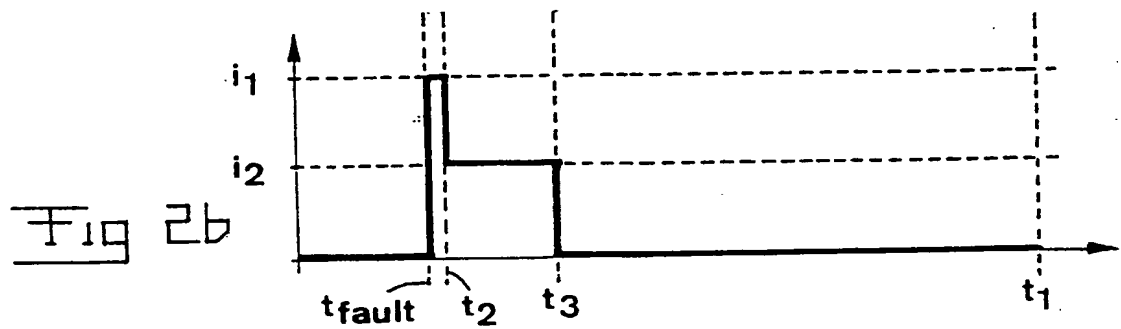
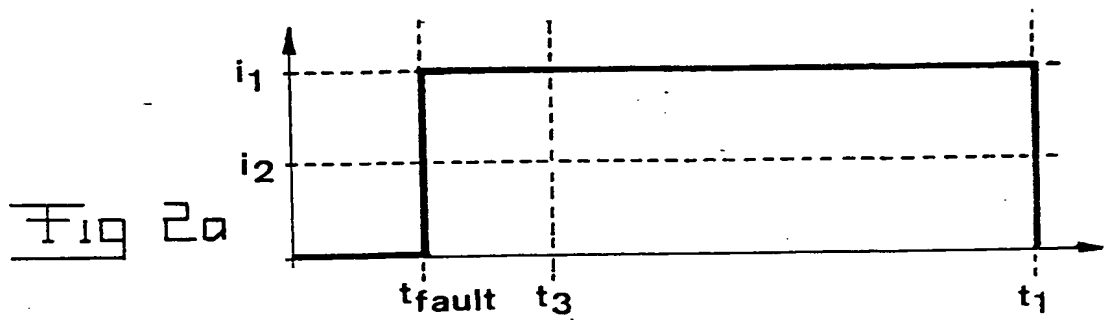
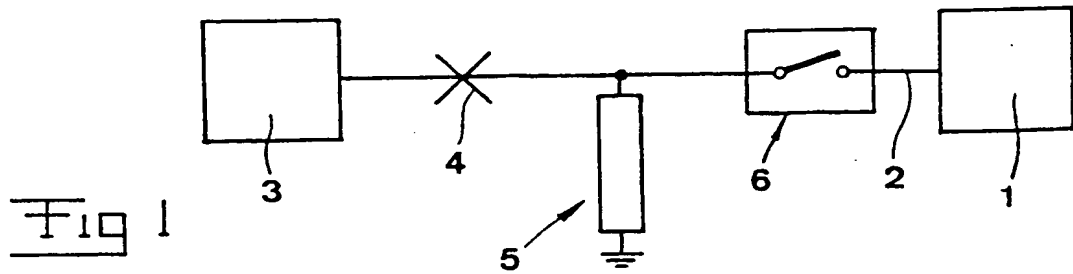
37. A method according to claim 36, characterized in that overcurrents are diverted to earth (8) or otherwise another unit having a lower potential than the network/equipment by means of the overcurrent reducing arrangement (5).

38. A method according to claim 36 or 37, characterized in that a breaker (6), which is arranged in the line between the switching device and the object and between the overcurrent reducing arrangement (5) and the object (1), is caused to break not until the overcurrent towards or away from the object (1) has been reduced by means of the overcurrent reducing arrangement (5).

39. A method according to any of claims 36-38, characterized in that the protection device comprising the overcurrent reducing arrangement (5) is coupled for protection of an object in the form of a transformer or reactor.

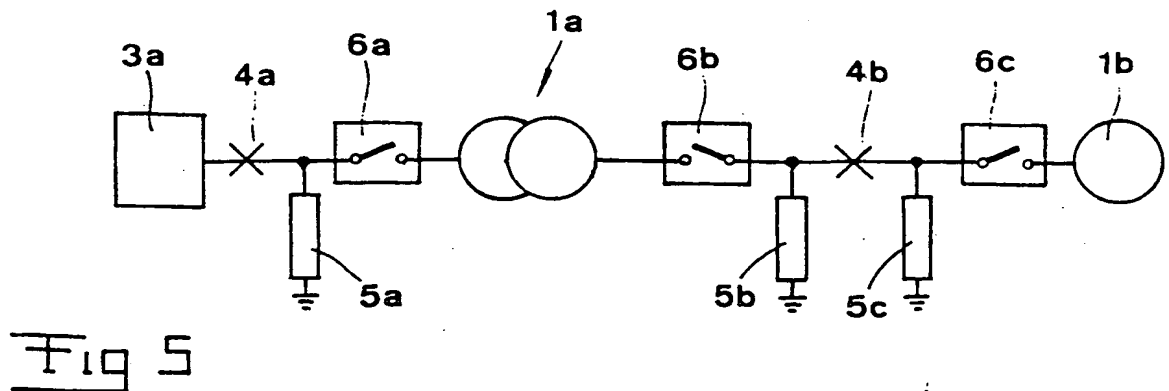
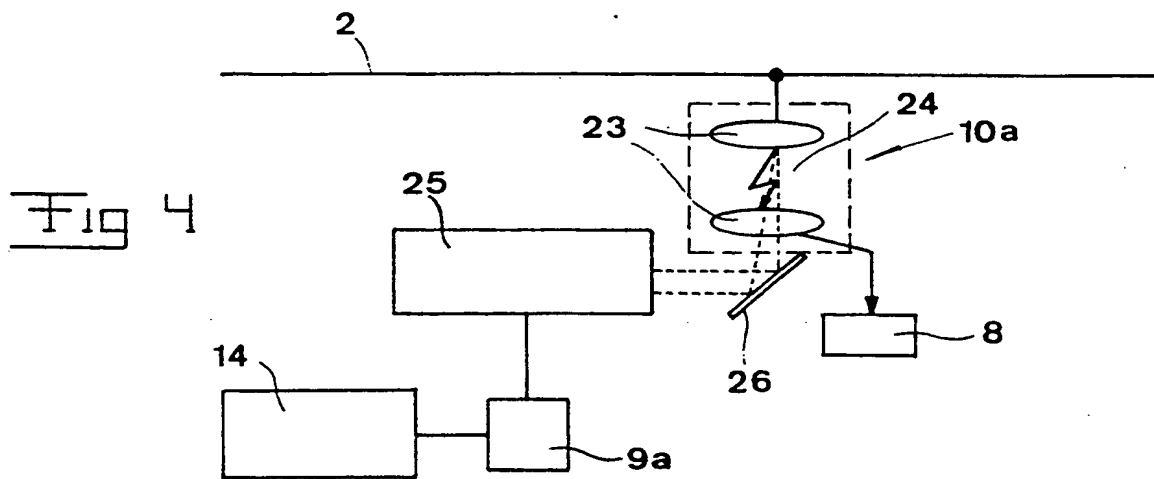
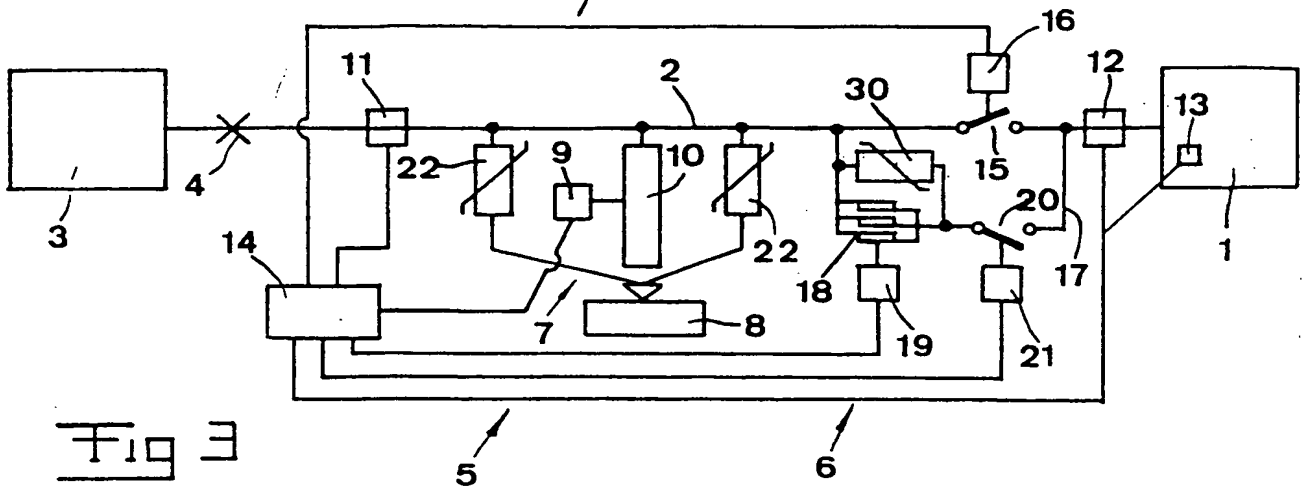
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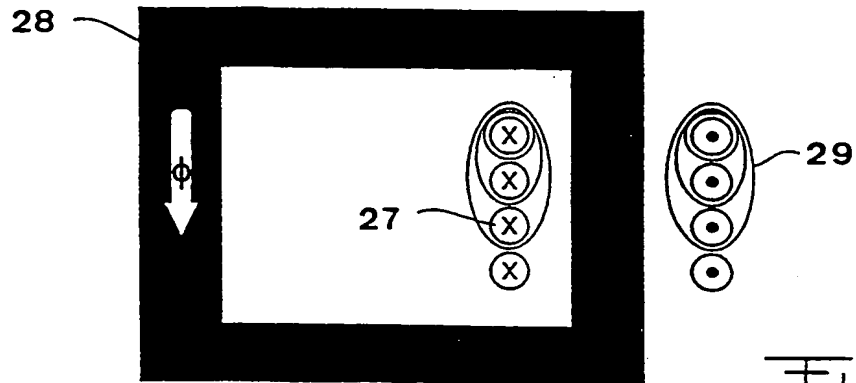


Fig 6

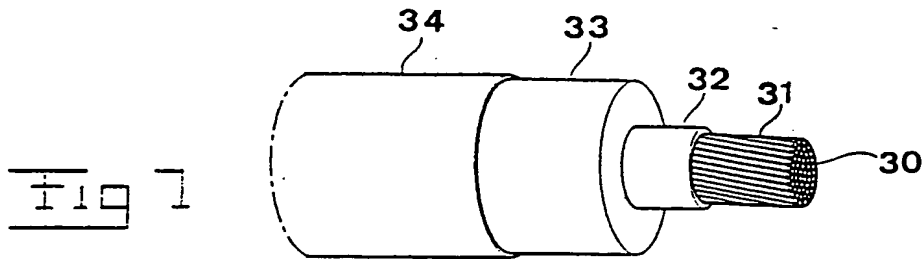


Fig 7

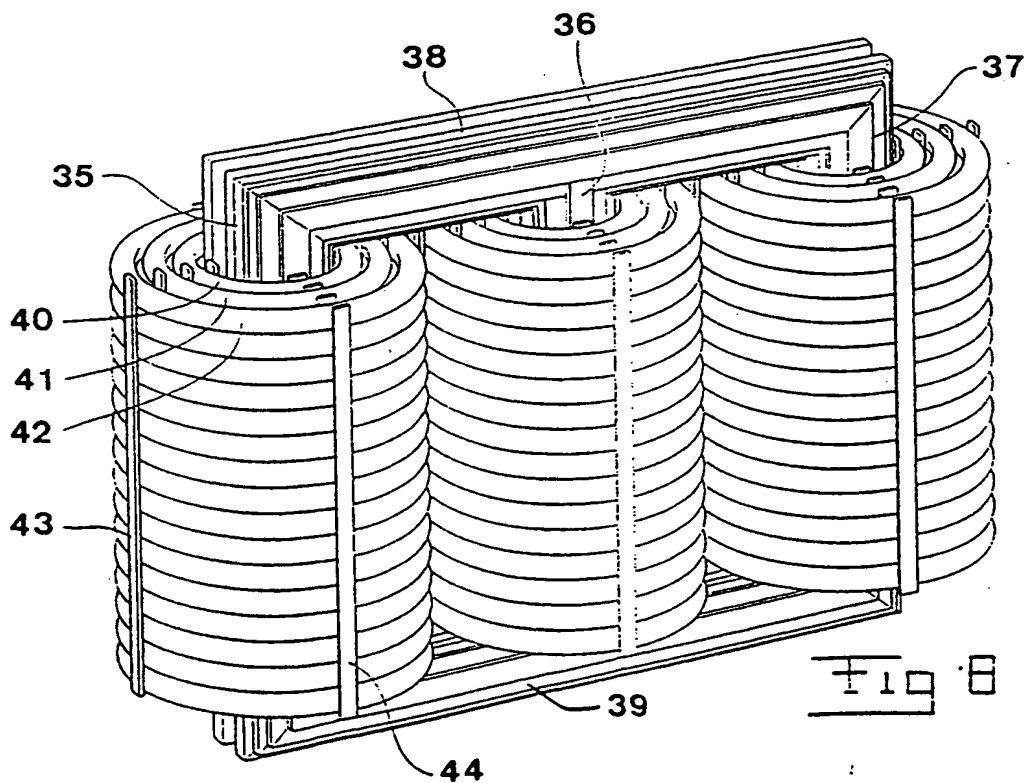


Fig 8

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 97/00882

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H02H 9/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: H02H, H01H, H02K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4184186 A1 (P. BARKAN), 15 January 1980 (15.01.80), column 1, line 60 - line 62; column 2, line 16 - line 29; column 2, line 44 - line 51, figures 1,2, column 4 line 20 - line 33, line 51-68,col.5-6,col.7,line 1-23,line 55-61	1-5,9,10, 17-23,32-39
Y	--	6-8,11-15, 24-31
A	EP 0280759 A1 (WESTFÄLLSCHE BERGGEWERKSCHAFTSKASSE), 7 Sept 1988 (07.09.88), column 4, line 30 - line 58, figure 1, abstract	5
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☒ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

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Date of the actual completion of the international search

2 December 1997

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 97/00882

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 3418530 A1 (W.H.CHEEVER), 24 December 1968 (24.12.68), figures 1,2, col.1, line 45-72, col.2, line 1-15 --	6,7
Y	US 5153460 A1 (L.J.BOVINO ET AL), 6 October 1992 (06.10.92), figures 1,2, abstract, col 1, line 12-14 --	8
Y	US 4164772 A1 (N.HINGORANI), 14 August 1979 (14.08.79), figures 1-7, col.1, line 5-14, col.2, line 10-68, col.3, line 1-5 --	11-14
Y	US 5452170 A1 (S.OHDE ET AL), 19 Sept 1995 (19.09.95), figure 2, abstract --	15
Y	US 5036165 A1 (R.ELTON ET AL), 30 July 1991 (30.07.91), figure 1, abstract, col.1, line 16-60, col.2 line 26-57 --	24-31
A	US 4134146 A1 (E.W.STETSON), 9 January 1979 (09.01.79), col.1, line 1-14 --	17
A	US 5136459 A (P.FARAROY), 4 August 1992 (04.08.92), col. 1 line 62-68 -----	21

INTERNATIONAL SEARCH REPORT

Information on patent family members

04/11/97

International application No.

PCT/SE 97/00882

Patent document cited in search report			Publication date	Patent family member(s)	Publication date
US	4184186	A1	15/01/80	NONE	
EP	0280759	A1	07/09/88	DE 3787798 D	00/00/00
US	3418530	A1	24/12/68	NONE	
US	5153460	A1	06/10/92	NONE	
US	4164772	A1	14/08/79	DE 2914313 A GB 2019099 A JP 54140157 A JP 56022208 B SE 7903270 A	25/10/79 24/10/79 31/10/79 23/05/81 18/10/79
US	5452170	A1	19/09/95	DE 4304863 A JP 5234471 A	26/08/93 10/09/93
US	5036165	A1	30/07/91	US 5066881 A US 5067046 A CA 1245270 A US 4853565 A	19/11/91 19/11/91 22/11/88 01/08/89
US	4134146	A1	09/01/79	CA 1121443 A	06/04/82
US	5136459	A	04/08/92	NONE	

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